LCA Case Studies

Life Cycle Inventory Study of the Electrical Energy Production in Romania

Nicolae Peiu

Environmental Protection Agency Iasi County, str. Vascauteanu nr. 10 bis, 700462 Iasi, Romania (nicolaepeiu2001@yahoo.com; ppri@apmis.ro)

DOI: http://dx.doi.org/10.1065/lca2007.05.333

Please cite this paper as: Peiu N (2007): Life Cycle Inventory Study of the Electrical Energy Production in Romania. Int J LCA 12 (4) 225–229

Abstract

Aim, Scope and Background. The paper proposes the assessment of the environmental interventions resulting from the electrical energy production in Romania, a Central East European country, using the LCA technique limited to a Life Cycle Inventory study (an LCA without the Life Cycle Impact Assessment phase).

Main Features. The following life cycles of the energy carriers employed in the production of the electrical energy are analysed according to their provenance: lignite (domestic) 31.2%, brown coal (domestic) 3.4%, brown coal (import) 0.4%, heavy oil (domestic, land) 4.2%, heavy oil (domestic, continental platform of the Black Sea) 0.4%, heavy oil (import) 3.6%, natural gas (domestic) 12.4%, natural gas (import) 6.1%, hydropower 27.8%, and nuclear energy 10.5% from the total of the electrical energy produced in Romania. The unit processes of the life cycles of these energy carriers are aggregated in two main stages: Pre-combustion (extraction, processing, transport and achievement of infrastructure) and Combustion (the production of electricity). The functional unit of the study is represented by 1 kwh. The spatial limits of the analysed system are extended as far as CIS countries for coal, Western Siberia (Russian Federation) for natural gas and the OPEC countries for oil. The temporal limits are included in the year 2000.

Results and Discussion. The LCI study enabled us to quantify the interventions on the environment, which result from the electricity production in Romania, the independent use of different energy carriers and the different life cycle stages of the system. The use of the LCA technique in a prospective way shows the reduction of these interventions that could be achieved through the adoption of specific scenarios for the development of electrical energy production in the country.

Conclusions. The main findings of this Life Cycle Inventory study, the first for Romania, are: the emissions of pollutant substances are prevailing in the combustion stage; for different energy carriers, the magnitude of environmental interventions decrease in the following order: coal, oil, natural gas, hydropower and nuclear energy. By comparison with other countries, the environment is more affected by the production of electricity in the case of Romania and only the promotion of alternative, renewable resources such as hydropower could substantially improve these interventions.

Recommendations and Perspectives. Some important interactions with the environment, like land use or the risks of the nuclear energy, are not taken into consideration in the study because of the lack of particular data for Romania. We would like to continue the investigation in order to surpass the limits of the study, on the one hand by collecting data concerning the risk of nuclear power or land use at the national level for different energy carriers or, on the other hand, by taking into account some other renewable resources like wind or solar energy.

Keywords: Combustion; electrical energy; energy carriers; Life Cycle Inventory study; pre-combustion; renewable resources

1 Aim, Scope and Background

The aim of the study presented in this paper is to contribute to the assessment of environmental interventions resulting from the electricity production in Romania. Electricity is present in many life cycle stages of products (services) and every country uses its own mixture of energy carriers in order to produce electricity. For this reason, it is important to achieve a sound evaluation of environmental burdens associated with the production of electricity at the country level from the LCA perspective. It is worth noticing that this study represents one of the items contributing to the implementation of the LCA in Romania, the main topic of a recently finished Ph D thesis [1].

2 Main Features

In order to achieve the goal of this study, it is suitable to limit the LCA technique to a Life Cycle Inventory (LCI) study (in conformity with the ISO14040 Standard a LCA without the Life Cycle Impact Assessment phase).

On the one hand, the study proposes the employment of LCA in a descriptive way (attributive LCA) for the presentation of environmental interventions resulting from the life cycle of the energy carriers used in the production of electricity in Romania. On the other hand, the LCA technique is applied in a prospective way (consequential LCA), in order to quantify the change of these environmental interventions after the adoption of several development scenarios for the production of electrical energy in the country.

The energy carriers used in the electricity production system in Romania are classified according to their provenance in **Table 1.**

Table 1: Energy carriers used in the mixture of electricity production in Romania (2000)

The energy carrier	Provenance	% from the total used
Lignite	domestic	31.2
Hard coal (brown)	domestic	3.4
Hard coal	import	0.4
Oil	domestic land	4.2
Oil	domestic sea	0.4
Oil	import	3.6
Natural gas	domestic	12.4
Natural gas	import	6.1
Hydropower	domestic	27.8
Nuclear power	domestic	10.5

Table 2: Main properties of the energy carriers used for the electricity production in Romania

Fuel	Low Heating Value MJ/kg	Low Heating Value MJ/m^3	%S	% Ash
Natural gas		33.65	0	0
Oil (heavy)	40.2		1.7	0.09
Hard coal import	25		1	19
Hard coal domestic (brown)	14.9		1	30
Lignite	7.4		1	41

In the year 2000, more than half (actually 61.7%) of the electrical energy in the country was produced using fossil fuels: coal, oil and natural gas. Hydropower contributes with 27.8% and nuclear energy with 10.5% The main properties of these energy carriers are presented in **Table 2**.

The unit processes of the energy carrier life cycles are aggregated in two main stages: Pre-combustion (extraction, processing, transport and the achievement of infrastructure) and Combustion (the production of the electricity). The functional unit of the study is represented by 1 kWh. The spatial limits of the analysed system are extended as far as the CIS countries (coal), western Siberia (Russian Federation) (gas) and the OPEC countries (oil). Temporal limits of the system are included in the year 2000.

Besides the five subsystems representing life cycles of the main energy carriers (gas, oil, coal, water and nuclear power), the complex system of the mixture of electricity production in Romania was divided into 16 processes according to the origin of fuels (domestic or import) and the cumulative stages of life cycle (pre-combustion and combustion). The final inventory table comprises data concerning 15 environmental parameters (cumulated energy requirement or primary energy, representing the total amount of the energy resources needed to deliver electricity, CO_2, SO_2, NO_x, CH_4, non-methanic volatile organic compounds, CO, N_2O, particulate matter, HCl and HF concerning air emissions, chemical oxygen demand and biological oxygen for water emissions and ash, and sewage sludge demand solid residues on soil) X 16 processes.

The data used in the study are extracted from the following sources:

- The National Statistical Year Book 2001 for Romania [2] for general data concerning the amounts of the energy carriers used for the production of electricity in Romania;
- The National Lignite Company Tg. Jiu, The National Hard Coal Company Petrosani for coal; the Rompetrol and Petrom companies for oil; Hydroelectrica company for hydropower and Nuclearelectrica company for the nuclear power for the pre-combustion step of these energy carriers produced in Romania;
- GEMIS database (Oeko Institute, Germany)[3] for the pre-combustion step of the imported energy carriers;
- Termoelectrica company [4], the main producer of electricity and heat from fossil energy carriers in the country, for the combustion step;
- GEMIS database (Oeko Institute, Germany)[3] for electricity production in EU-15 and USA;
- the Road Map in the Field of Energy for the accession of Romania in EU [5] and the Strategy for the Development of the Energy in Romania on medium-term [6] for the basic scenarios on medium and long-term;
- a study concerning the development of nuclear and hydropower in Romania [7], for the sustainable development scenario.

The average efficiency of the electrical energy production for different energy carriers in the year 2000 was: 38.7% for natural gas and oil power plants, 32.9% for hard coal power plants, 25.6% for lignite power plants, 100% for hydropower and 33% for nuclear power [4].

It is also worth mentioning that the analysis takes into account only the electrical energy provided by the producer, without the energy that reaches the consumer.

3 Results and Discussion

3.1 Interventions on the environment at the level of the year 2000

In the first place, the results of using the LCA technique in a descriptive way concerning the environmental interventions from the electricity production in Romania in the year 2000 are summarily presented below in order to emphasise:

(1) The distribution of interventions on the environment between the two main stages of the life cycle (pre-combustion and combustion) presented in **Figs. 1**and **2**. The emissions of the main polluting substances are unevenly distributed between these two stages prevailing in the combustion stage. Thus, the CO_2 emissions in the pre-combustion stage represent only 3.7%, SO_2 emissions 1.7% and total particulates 0.28% from the total emissions of these substances. It

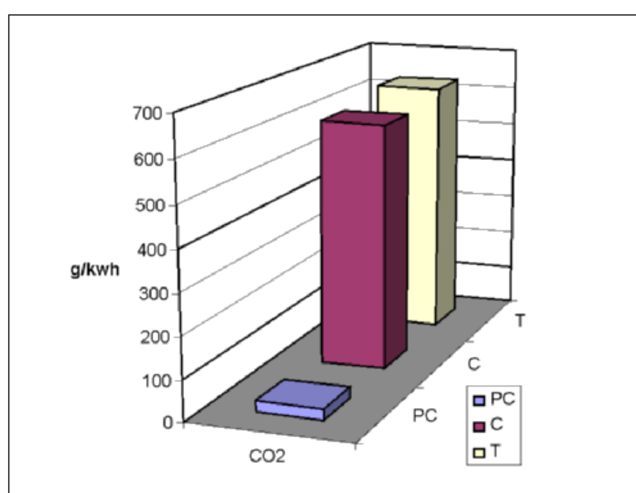


Fig. 1: The distribution of environmental interventions between the steps of the Life Cycle. a) Emissions of CO2 in the life cycle stages. Legend: PC=pre-combustion; C=combustion; T=total

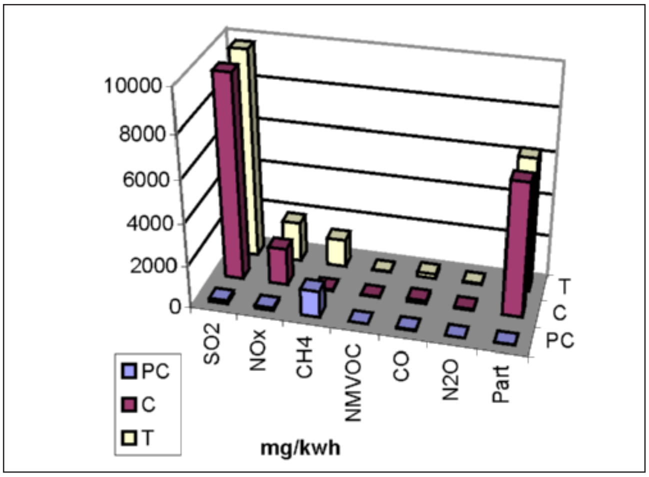


Fig. 2: The distribution of environmental interventions between the steps of the Life Cycle. b) Emissions of other pollutants in the life cycle stages. Legend: PC=pre-combustion; C=combustion; T=total; NMVOC=non-methanic volatile organic compounds; Part=particulate matter

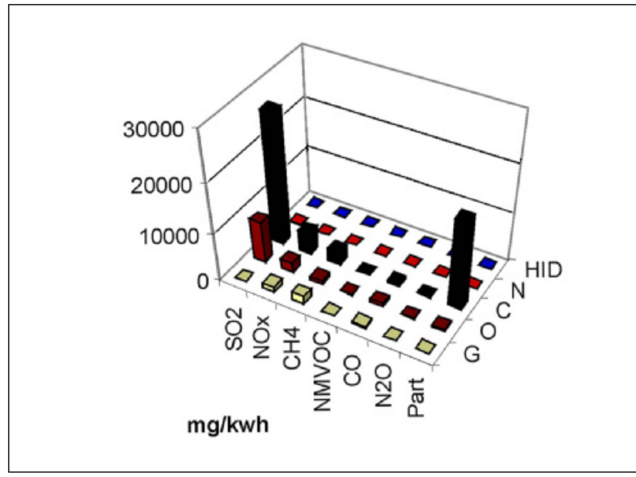


Fig. 4: Comparison between pollutant substances resulted from different energy carriers. b) emissions of other pollutants. Legend: G=gas, O=oil, C=coal, N=nuclear, HYD=hydropower, NMVOC=non-methanic volatile organic compounds, Part=particulate matter

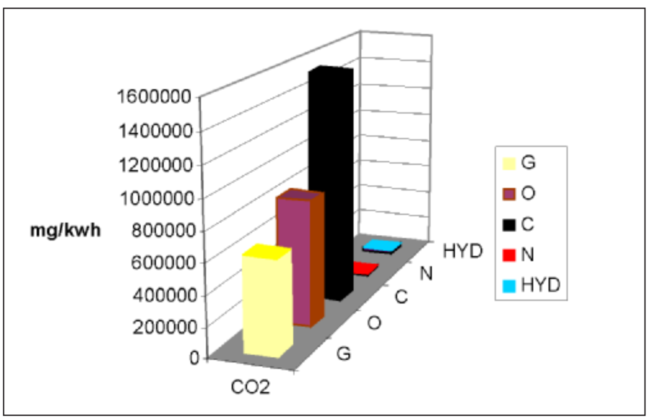


Fig. 3: Comparison between pollutant substances resulted from different energy carriers. a) emissions of CO_2. Legend: G=gas, O=oil, C=coal, N= nuclear, HYD=hydropower

is only in the case of methane that the emissions in the pre-combustion phase are prevailing, reaching 97.7% from the total of methane emission.

The sources of these methane emissions in the pre-combustion step are coal extraction (mainly the ventilation of coal mines) and fugitive emissions from the extraction and distribution of natural gas.

(2) The comparison between the environmental interventions resulted from the 5 analysed subsystems representing the energy carriers life cycles for the electricity production presented in **Figs. 3** and **Fig. 4**.

These figures show that, in the comparison between different energy carriers, the magnitude of environmental impact decreases in the following order: solid fuels, heavy oil, natural gas, hydropower and nuclear energy. Thus, in the case of CO_2, the emissions for coal reach 1546.26 g/kWh, in comparison with 834.74 g/kWh for heavy oil, 624.61 g/kWh for natural gas, 20.32 g/kWh for hydropower and 13.26 g/kWh for nuclear energy.

(3) A comparison between the interventions resulted from the complex system of electrical energy production in Romania and the same systems at the level of EU-15 and USA. **Fig. 5** presents the energy carriers which were used for the production of the electricity in EU-15 and USA.

The system of electricity production in the USA is closer to that in Romania as far as the usage of fuels is concerned, even though the USA uses more fossil fuels (73%, from which 53% is coal). EU-15 uses a combination which is safer for the environment (34% nuclear energy, 12% hydro-energy and 33% natural gas).

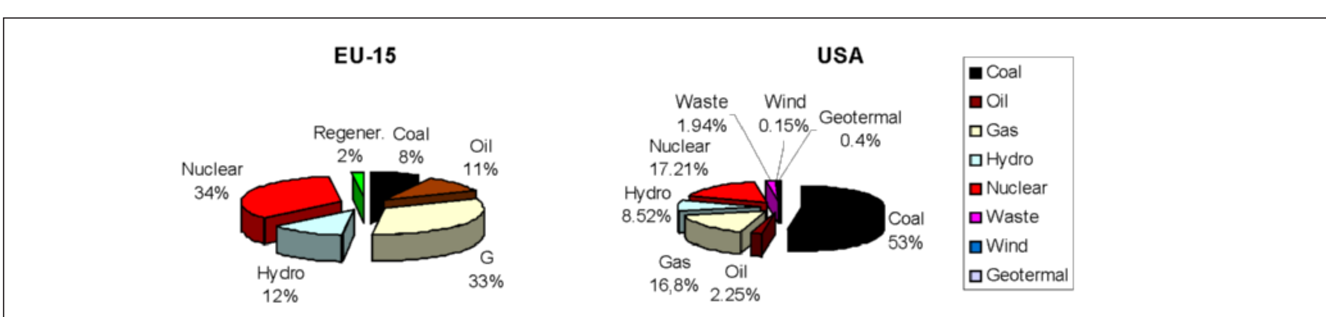


Fig. 5: Energy carriers used in the mixture of electricity production in EU-15 and USA (data from GEMIS database) (2000)

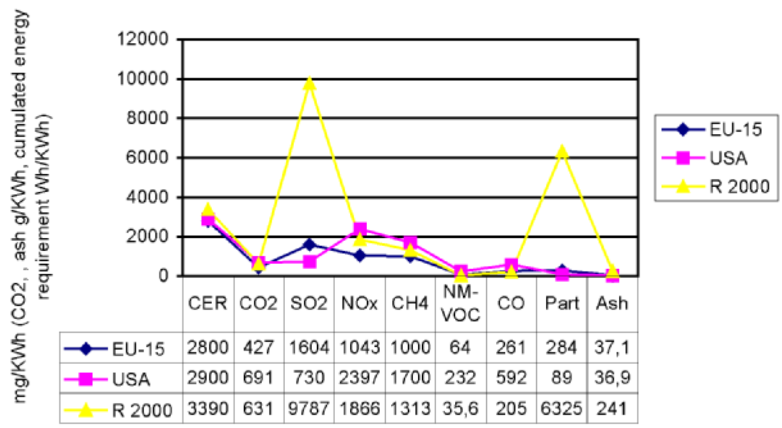


Fig. 6: Comparison between environmental interventions in EU-15, USA and Romania (2000). Legend: CER=cumulated energy requirement, NM-VOC=non-methane, volatile organic compounds, Part=particulate matter

Fig. 6 presents a comparison between the emissions of main pollutant substances and the cumulated energy requirement resulted from the electricity production in Romania, EU-15 and USA.

The emissions are greater in Romania than in the United States of America due to the fact that many of the power plants are obsolete and have a low efficiency. EU-15 uses cleaner energy carriers than Romania and, because the power plants have a high efficiency, the emissions that result are lower than in the USA and in Romania.

3.2 Interventions on the environment after the adoption of some development scenarios

Secondly, the LCA technique is used in a prospective way (consequential LCA), in order to quantify the change of the environmental interventions after the adoption of the following three scenarios for the development of the electrical energy sector in the country:

a) the basic scenario on medium-term (2007);
b) the basic scenario on long-term (2015);
c) the sustainable development scenario on long-term (2020).

It is a great probability for the two basic scenarios which are not alternative but consecutive to be almost entirely achieved, because they comprise the following measures from the Road Map in the Field of Energy for the accession of Romania in EU [5] and the Strategy for the Development of the Energy in Romania on medium-term (2004)[6]: the doubling (first scenario) and three-fold increase (the second scenario) of the nuclear energy for the completion of the second and third unit of the Cernavoda nuclear power plant, the decommissioning of some old power plants and the modernization of the others that use brown coal or lignite; the adoption of new technologies like combined cycle gas turbines or end-of-pipe control technologies like flue gas de-sulfuration.

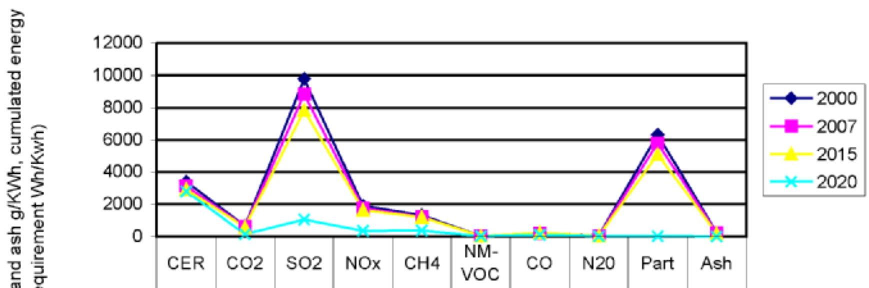
After the adoption of these two scenarios, fossil energy carriers will further dominate the complex system of electricity production in Romania.

In exchange, the sustainable scenario, which represents an alternative to the fundamental scenarios, proposes the long-term development of hydropower in such a way that the degree of employment of this renewable resource will be doubled, reaching 80% from the total hydropower potential of the country in 2020 [7]. The adoption of the sustainable development scenario allows the country to suspend the extraction of lignite and hard coal and the importation of hard coal and heavy oil. After the adoption of the fundamental scenario on medium-term, the efficiency of electricity production increases with 2.6%; while, after the adoption of the fundamental scenario on long-term, the efficiency of electricity production increases with 4.9% and; after the adoption of the sustainable development scenario, the efficiency of electricity production increases with 6.4% by comparison with the level from the year 2000.

The new combination resulted after the adoption of these three scenarios is presented in **Table 3**.

Table 3: The basic scenarios on medium (2007) and long-term (2015) and the sustainable development scenario (2020) for the improvement of the system of electricity production in Romania

The energy carrier	Provenance	Fundamental scenario on the medium term (2007) (in %)	Fundamental scenario on long term (2015) (in %)	Sustainable development scenario (2020) (in %)
Lignite	domestic	28.3	24.7	0
Hard coal (brown)	domestic	3.8	3.3	0
Hard coal	import	0.8	0.4	0
Oil	domestic land	4.2	4.2	4.2
Oil	domestic sea	0.4	0.4	0.4
Natural gas	domestic	12.4	12.4	8.0
Natural gas	import	6.3	7.9	8.0
Hydropower	domestic	26.9	24.7	57.4
Nuclear power	Domestic	16.9	22.0	22.0



	CER	CO2	SO2	NOx	CH4	NM-VOC	CO	N20	Part	Ash
2000	3390	631,1	9787	1886	1313	35,55	205,2	56,35	6325	240,9
2007	3120	600,6	8837	1751	1203	33,33	202,9	52,46	5794	221
2015	2908	576,7	7851	1624	1193	36,82	215,5	47,38	5089	194
2020	2789	149,3	1053	342,8	366,7	22,12	118,8	19,54	19,1	0,2

Fig. 7: The environmental interventions at the present (2000) and after the adoption of the proposed scenarios. Legend: CER=cumulated energy requirement; NM-VOC=non-methane volatile organic compounds; Part= particulate matter

The analysis of environmental interventions after the adoption of these scenarios is presented in **Fig. 7**.

Environmental emissions are decreasing gradually on the way from the fundamental scenario on short-term a) to the sustainable scenario c). But, the decrease of the emissions and the primary energy resulting after the adoption of the basis scenarios are only cosmetic, insignificant by comparison with the reference level from the year 2000. Romania can enter 'the select club of clean energy producer countries' like Norway, Sweden or Switzerland, only after the adoption of the sustainable development scenario and the reduction of the emissions.

4 Conclusions

The LCI study of electrical energy production in Romania presently shows that, because of the predominant use of the fossil energy carriers (especially coal) and the low efficiency of the power plants, the interventions on the environment resulting from this process are significant even in comparison with other countries that use more fossil fuels, like the USA. The analysis of the burdens on the environment resulted from the independent use of different energy carriers demonstrates a decrease in the size of the impact in the order: coal, oil, natural gas, hydropower and nuclear power. Concerning life cycle steps, pollutant substances are emitted prevailing in the combustion stage, except for the methane that is predominant in the pre-combustion stage because of the emissions in the processes of coal and natural gas extraction and natural gas distribution. The prospective use of LCA shows the level of the decrease of the interventions on the environment resulting from the adoption of different scenarios for the improvement of the mixture of the energy carriers and the efficiency of power plants. Substantial improvement for the environment can only be achieved through the promotion and use of alternative renewable resources such as hydropower.

5 Recommendations and Perspectives

Some important interactions with the environment, like land use or the risks of the nuclear energy, are not taken into consideration in the study because of the lack of particular data for Romania. There are numerous debates, generated by the risks of the nuclear power and by the fact that coal, oil, gas extraction or hydropower could cause through the land-use, important impacts on the landscape or biodiversity. We would like to continue the investigation in order to surpass the limits of the study, on the one hand, by collecting data concerning the risk of nuclear power or land use at the national level for different energy carriers; on the other hand, by taking into account some other renewable resources like wind or solar energy.

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Received: September 29th, 2005
Accepted: May 7th, 2007
OnlineFirst: May 8th, 2007